International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 12, December-2014

Performance Investigation of Offset Parabolic Solar Cooker for Rural Applications

Haftom Asmelash
School of mechanical and industrial engineering
Mekelle University, Ethiopia

Mulu Bayray
School of mechanical and industrial engineering
Mekelle University, Ethiopia

Ashenafi Kebedom
School of mechanical and industrial engineering
Mekelle University, Ethiopia

Anwar Mustofa
School of mechanical and industrial engineering
Mekelle University, Ethiopia

***Abstract*— Energy for cooking is one of the basic uses of energy in many parts our globe. Many developing countries use fuel wood as energy sources for cooking, backing and heating thus leading to environmental pollution, deforestation, ecological deterioration and consequent drought and famine. Solar energy can be one important alternate energy source if, even, a portion of it is harnessed for cooking applications. For efficient utilization of solar energy, an offset type of concentrating collector was designed and manufactured for a cooking purpose having major and minor diameters of 90 by 80 cm respectively. It was tested for its thermal performance following standard testing procedures of the American Society of Agricultural Engineers (ASAE) and the system was found useful with an encouraging results. Maximum temperature of 94^{0}C was achieved in 25 minutes on the water in the cooking vessel. The standardized cooking power for a temperature difference of 50^{0}C was found to be 40 W.**

Keywords—concentrating collector; ASAE; cooking power; solar energy; offset concentrator

I. INTRODUCTION

The increasing demand for fuel and the scarcity of alternative sources is a major factor leading to deforestation. In many African countries urban growth has created a great demand for charcoal resulting in a loss of some large hectares of forests annually through fuel wood extraction. Fuel wood supply to Cities alone had been depleting forests in the surrounding areas at alarming rate. Consequently, today in some African countries, charcoal is brought from distances of up to 200 km inland [1]. The gradual disappearance of woodland in areas around towns has also been observed in many African countries. The major effects of deforestation have been deterioration of ecological systems, with resulting negative impacts on soil fertility, water flows and biological diversity. Soil erosion has become a serious problem in many parts of Africa. Sheet and gully erosion are widespread, rendering most of the land unproductive.

In countries like Ethiopia, using fuel wood as source of energy is not only affecting the economy of the country, through negative effects on agriculture, but also the health of the people.

Solar energy will be one of the important alternate energy sources if a portion of it is effectively harnessed, especially for the day to day life [2].The energy from the sun has to be first concentrated using a reflecting arrangement of mirrors or lenses. Concentration of solar radiation can be achieved by using different types of devices such as flat plat collectors, photovoltaic cells and concentrating collectors. In the last few years, significant advances have been made in the development of concentrating collectors and a number of types have been commercialized [3].

Among the different energy end uses, energy for cooking is one of the basic and dominant end use in developing countries. Most of the densely populated countries are blessed with abundant solar radiation with a mean solar radiation in the range of 5-7 kWh/m^2 [4]. In countries like Ethiopia every day is a sunny day; hence solar cookers have high potential and offer a viable cooking energy option. They present an alternative, safe and convenient way to cook food without consuming fuels and polluting the environment. Different types of solar cooker have been developed which are being promoted in many countries. These include solar box cookers, parabolic dish solar cookers, "cookit" etc. [5].

Principles of cooking

Solar cookers work on the principles of absorption of light and conversion into heat. The solar radiation energy needs to be collected from a large area so that higher temperatures, higher than the ambient, can be obtained. The collected radiation should be supplied to a smaller area. The collection of light from large area and its application to smaller area is the concentration ratio. In this regard, the geometric concentration ratio ***CR*** is defined as [6]:

$$CR = \frac{A_t}{A_{rc}} \quad (1)$$

Where $\boldsymbol{A_t}$ is the total collector area and $\boldsymbol{A_{rc}}$ is the area of the receiver/absorber surface

In solar cooking, since the utensil is exposed to concentrated radiation, it absorbs more energy than the case when it is exposed to non-concentrated light. Due to exposure to concentrated light, a cooking vessel attains higher temperature than the ambient, which makes solar cooking possible. The methods of cooking food are by boiling, frying, roasting and baking. In case of cooking food by boiling such as rice and lentils, the temperature of the food being cooked should be about 100^{0}C [7].

IJERT

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

In this paper an effort has been made to utilize the energy from the sun for a cooking purpose. Keeping in mind rural people's food habits an efficient offset cooker has been adopted from previous designs and fabricated from easily available and low cost local resources. The efficiency and performance of the solar cooker were tested following standard testing procedures of the water boiling test of the American Society of Agricultural Engineers, ASAE S580 JAN03.

II. DESCRIPTION OF THE OFFSET PARABOLIC CONCENTRATOR

A. The parabolic dish

The prototype fabricated was an offset or off-axis parabolic dish type. This offset parabolic concentrator, sometimes called Scheffler collector, is a three dimensional dish shaped structure in which the focus point is located outside the collector area. Unlike most other parabolic dishes this offset dish has elliptical shape whose deepest point lies closer to one of the edges along the major diameter of the ellipse as shown in figure 1. Offsetting the focal point from the centre reduces burns and eye damage for the cook. Putting the cooking vessel around the focus area completely blocks reflected rays from reaching the cook hence avoids reflection for the person cooking. Table 1 shows dimensions of the parabolic dish.

To avoid complexity of design and for ease of manufacturing, an already readymade TV antenna which can easily be found in any country is also possible to use [8].

With this arrangement it is possible to reduce wind resistance and increases stability of the structure because of low centre of gravity. It also produces vertically reflected rays to reach the food pot at the bottom like in conventional stoves; moreover the pot placed at the focus does not create shadows over the reflecting surface. The inner surface of the offset dish that faces the sun is covered with aluminium foil, highly reflective material whose reflectivity ranges from 92 to 96%.

The reflective material should be cut in such a way that there were no wrinkles when they are glued to the surface of the dish, hence rectangular pieces of 10 cm wide was the optimum cut size for the offset parabolic dish.

TABLE I. DIMENSIONS OF THE OFFSET PARABOLIC DISH

Measurement		Dimension
Major diameter		900 mm
Minor diameter		800 mm
Depth at deepest point		70 mm
Distance of deepest point from the bottom edge along the major diameter		386 mm

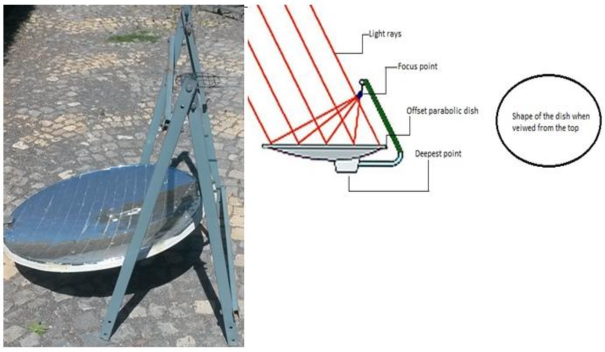

Fig. 1. The offset parabolic dish

B. The support frame

This is the structure which firmly supports the receiver, parabolic dish, cooking stand and pot. It was made from RHS, angle iron, bolts and nuts which are easily available materials in nearby places. The structure is made to join together by simple bolts and nuts hence easy to completely disassemble for transportation as in figure 2.

A joint and handle mechanism was used to effectively manoeuvre the dish along the vertical and horizontal plans in order to track the sun at different hours of the day. Tracking should be made every 10 minutes so as to focus the reflected rays on the cooking vessel

III. METHODOLOGY

A procedure for testing the solar cooker was developed based on existing international testing standards. A review of three commonly used international standards was made; the American Society of Agricultural Engineering Standards (ASAE S580, JAN 03) [9], Bureau of Indian Standards Testing Method and European Committee on Solar Cooking Research Testing Standards and others.

A. Adopted test procedures and experiments carried out

In all the testing standards reviewed, it is recommended that the necessary conditions that must be fulfilled prior to and during testing are environmental factors, controlled factors and measurement standards. With regard to environmental factors, the testing of solar cooker must rely, to some degree, upon the weather and climate of the testing site. The factors that were considered for the tests are wind speed, ambient temperature, insolation and precipitation. Controlled factors represent the portions of the test that are controlled by the tester. These factors can have a significant impact on the obtained results. Controlled factors that were considered are cooking vessels, tracking time, thermal loading and data collection and recording.

The solar cooker was tested outdoor in Mekelle University, North13^{0} 28' 52" and East 39^{0} 29' 7", Ethiopia in the months of October and November which are characterized as months receiving low insolation levels compared to the other months of the site. All these tests were conducted as per the guidelines of the American Society of Agricultural Engineers (ASAE) [9].

IJERT

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

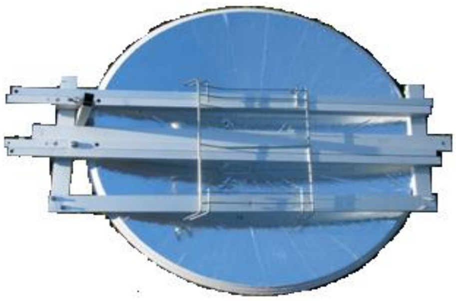

Fig. 2. Solar cooker disassembled

The cooking vessel, painted black as in figure 3, was made of inexpensive aluminium. Before putting this vessel on the focus area it was loaded with 7000 grams of potable water per square meter intercepted area distributed evenly as per the guideline of the ASAE; that is half a liter of potable water initially at room temperature was loaded to the cooking vessel.

Global radiation, ambient temperature and the temperature of the water in cooking pot were the measured variables using:

- Sunlight meter: a portable high tech RE LA-1017 model digital pyranometer was used to measure the radiation. It measures the global radiation in either watts or BTUs with an accuracy of +/- of 5%.
- Model TR-71Ui temperature sensor data logger: a USB type data logger that enables the downloading of recorded temperature by connecting directly to a PC. It has two channels; channel one for recording the ambient temperature and channel two for recording the water temperature in the cooking stove. It has an accuracy of +/- 5%
- Anemometer: the testing site's wind speed was measured using anemometer.

B. Calculating the cooking power (ASAE)

The cooking powers for each ten minutes interval have been calculated by multiplying the change in water temperature by the specific heat capacity of water in the cooking vessel and the mass of water; and results were divided by 600 seconds contained in a ten-minute interval, as:

$$P_i = (T_2 - T_1)MCv/600 \quad (2)$$

Where: P_i = cooking power (W), T_2 = final water temperature, T_1 = initial water temperature, M = water mass (kg), C_v= heat capacity (4186 J/[kg·K])

Fig. 3. Cooking vessel

These cooking powers were corrected into a standard insolation of 700 W/m^2 [9] hence the standardized cooking powers for each intervals were found using equation 3. Figure 7 shows plot of the adjusted cooking power and temperature differences with the regression line.

$$P_s = P_i\,(700/I_i) \quad (3)$$

Where P_s = standardized cooking power (W), P_i = interval cooking power (W) as calculated in equation 2 and I_i = interval average solar insolation (W/m2)

IV. Results and Discussions

The maximum temperature reached under the specified conditions was 94^{0}C which water normally boils in the place where the experiments were conducted. This water boiling temperature was attained in 25 minutes and was possible to maintain this boiling temperature until 4:30 p.m.

Referring to figure 4 the maximum insolation was 709 W/m^2. The insolation is low in the morning and late afternoon hours and hence is not convenient for solar cooking. It was observed that there was high and stable solar insolation between 9:10 a.m. to 4:30 p.m., from 705 W/m^2 to 1000 W/m^2, thus showing good time for cooking with this offset parabolic solar cooker. For all the experiments the average wind speed was recorded to be 3 m/s throughout the experiment.

The same experiments have been conducted in October and November 2013. Results of these experiments are shown in figures 5 and 6 respectively. It can be seen that the temperature profiles have the same trend. In both cases the time response was very fast; that is the temperature increased sharply to its maximum value, 94^{0}C, within 25 minutes then remained steady for much of the testing time. Looking at figure 5 below the radiation goes up and down but the change in temperature of the water in the cooking vessel is similar to the other experiments, thus it can be concluded that once the radiation level reaches 600 W/m^2 it will generate sufficient heat to boil water at the cooking vessel.

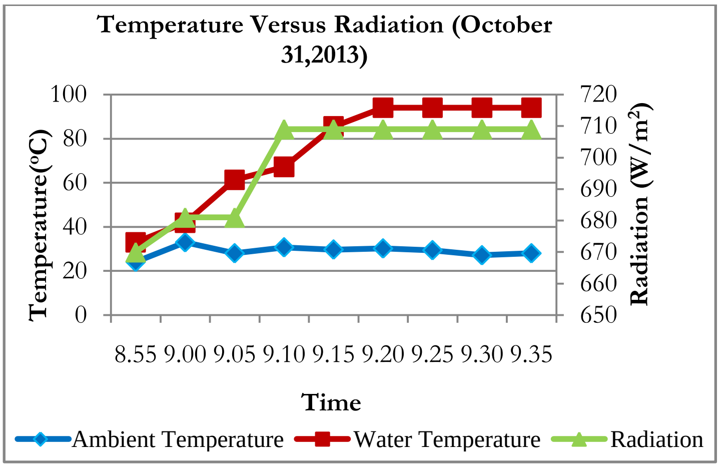

Fig. 4. Water temperatures and insolation against time measured on October 31, 2013

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

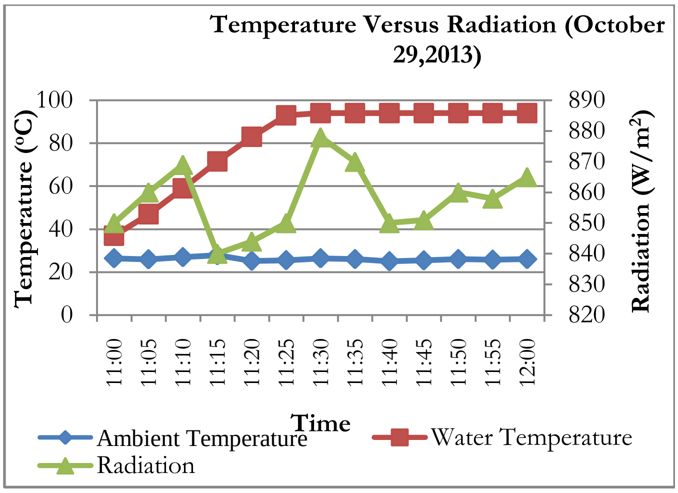

Fig. 5. Water temperatures and insolation against time measured on October 29, 2013

The cooking power

The value of the standardized cooking power for a temperature difference of 500C is found to be 40 W. This value is found using the linear regression line generated from figure 7. The R^2 was found to be 0.9 showing that there is good correlation between the temperature difference and the cooking power. This value, though provides consumer with a useful tool for comparison and product selection, does not guarantee of performance.

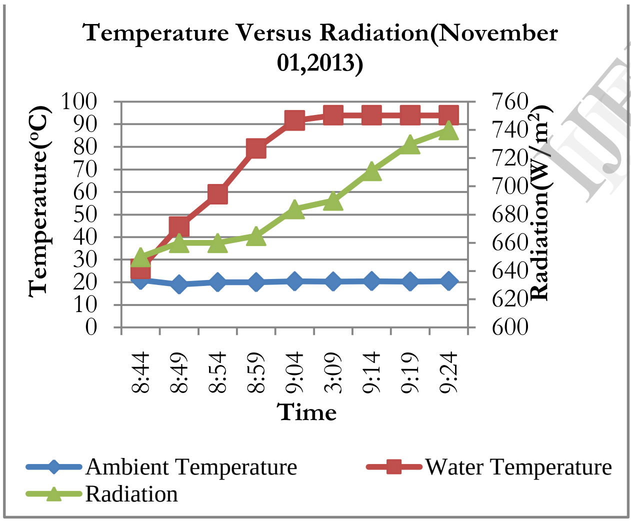

Fig. 6. Water temperature and insolation against time measured on November 1, 2013

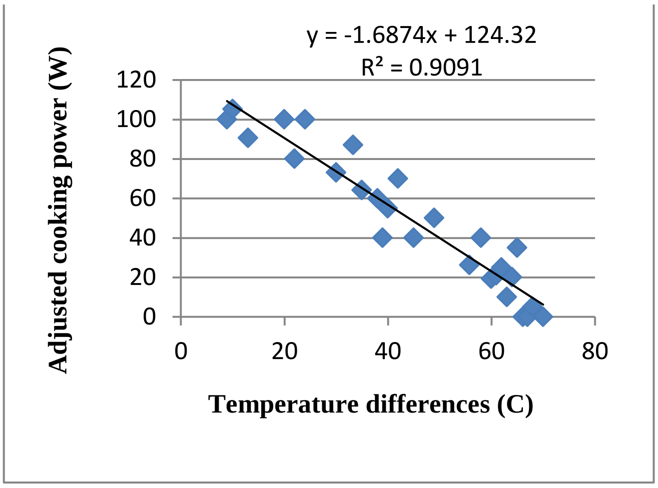

Fig. 7. Adjusted cooking power plotted over temperature difference and the resulting regression line

V. CONCLUSIONS

Lucky enough, most of the densely populated countries are blessed with abundant solar radiations with the range of 5-7 kWh/m^2; hence solar cookers can have high potential and offer a viable cooking energy option.

In this paper efficiency and performance of an offset parabolic cooker that was developed and manufactured from easily available materials and local technologies was measured following the American Society of Agricultural Engineers.

IJERT

94^{0}C, which is the boiling point of water on the test site, was the maximum temperature of the water on the cooking vessel. This temperature was achieved in less than 30 minutes and was possible to maintain it until 4:30 p.m. The good time for cooking with this cooker was observed between 9:10 a.m. to 4:30 p.m. that is when there is an insolation level of 705 W/m^2 to 1000 W/m^2.

Finally the adjusted cooking power versus temperature difference was plotted; resulting R-squared value shows that there is a good correlation between the temperature difference and cooking power.

REFERENCES

[1] C. Z. M. Kimambo, "Development and performance testing of solar cookers," Journal of energy in Southern Africa. Vol. 18, 2007

[2] R. Yogsh, S. B. Thombre, "Performance evaluation of parabolic solar cooker for indoor cooking," ISOR-JMCE, Vol. 4, 2013

[3] S. P., Sukhatem, J. K. Nayak, "Solar energy," McGraw Hill. Third edition, 2013

[4] R. M. Muthusivagami, R. Velraj, R. Sethumadhvan, "Solar cooker with and without thermal storage," A review. Renew Sustain Energy Rev, 2009.

[5] Solar cooker international, Solar cooker review. USA, Vol. 9, 2003

[6] J. Twidell, and T. Weir, "Renewable energy resources," Saurabh printers Pvt.Ltd. New Delhi, Second edition, 2013

[7] C. Singh, "Renewable energy technologies," PHIL learning Pvt. New Delhi, third printing, 2009

[8] J. Diz-bugarim, "Design and construction of low a cost offset parabolic solar concentrator for solar cooking in rural areas," ISES Solar World Congress, Germany, 2011

[9] ASAE S580, "Testing and reporting solar cookers performance," 2003

(This work is licensed under a Creative Commons Attribution 4.0 International License.)